DIGESTIBILITY STUDIES WITH DAIRY CATTLE

USING THE CHROMIUM OXIDE

INDICATOR TECHNIQUE

By

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INTRODUCTION

The effect on the digestibility of the nutrients and of the total ration when feeds are mixed in different proportions and amounts is of interest both to the scientist and to the herdsman. Results of a number of experiments indicate that the digestibilities of feeds are altered when two or more feeds are mixed in various combinations.

Watson (50) uses the term, "associative digestibility" or associative effect, to mean a change in digestibility of a feed due to its incorporation in a ration with one or more other feeds, and he gives the credit for its introduction to Ewing and Wells (11).

Plane of nutrition may be associated with changes in proportion of feeds in a ration and may affect digestibility of the feed or feeds.

The practicability of using indicator methods of determining digestion coefficients has been studied, and chromium oxide has been reported by several research workers to be a satisfactory indicator. All workers in this field are not in agreement, however.

The purposes of this experiment were first to determine digestibilities of rations composed of varying proportions of hay, silage, and grain, and secondly, to gain experience with, and observe the practicability of, the chromium oxide indicator technique.

REVIEW OF LITERATURE

Digestion coefficients may differ when feeds are fed separately or in combination. Knowing what these differences may be and thus being able to correct for them is important to the scientist and the herdsman.

Forbes and Swift (14) felt that associative effects of feeds as defined in the introduction seemed to be due to the difference in growth of microorganisms, digestible constituents of their bodies, and digestible products of their vital activities. Of course, the differences in microorganisms are caused by changes in the type of food available to them. According to these workers, coarsely ground corn was 23.8% more digestible for steers when fed with alfalfa hay than when fed with timothy hay. Corn was less digestible when fed with a basal ration containing alfalfa hay and corn than when fed with a basal ration of all-alfalfa hay.

These workers noted that protein digestibility was lower and ether extract digestibility was higher when alfalfa and timothy hay were fed in combination than when each hay was fed separately. The digestion coefficients of the other nutrients were the same regardless of the way of feeding. When alfalfa silage was preserved with either molasses or phosphoric acid and added separately to a basal ration of alfalfa hay, corn meal, and linseed oil meal, the alfalfa-molasses silage was the more digestible of the two. Neutralization of the phosphoric acid by the addition of pulverized limestone resulted in an increase in its digestibility.

Forbes et al. (13) indicated that corn meal digestibility was not materially affected by feeding to steers in combination with hay. However, the data showed a 7% decrease in protein digestibility, a 17.9% decrease in ether extract digestibility and an increase of 3.5% in the digestibility of nitrogen-free extract when the corn meal was fed in a 1:1 ratio with hay in a maintenance ration as compared to corn fed separately. The metabolizable energy of corn meal was the same when fed alone or in combination with hay. The net energy value of corn meal was higher when it was fed in combination with hay than when corn was the sole ingredient of the ration.

According to Ewing and Wells (11), the digestibility of nitrogen and of crude fiber was depressed, while that of ether extract was increased, when excessive starch was fed in combination with corn silage. When cottonseed meal was added to a high-starch ration, these effects were not observed. Increasing the fiber by adding silage increased nitrogen-free extract digestion. Dry matter was more digestible when silage and cottonseed meal were fed in a 50:50 ratio than when they were fed at ratios of 7:3 or 3:7. It was found that cottonseed meal was slightly, but not significantly, more digestible when fed in combination with corn silage than when fed alone. Greater digestibility would seem reasonable because the combination would be a better balanced ration than when either was fed separately.

Ewing, Wells, and Smith (12) observed that total dry matter digestibility was lower when corn silage and cottonseed meal were fed to steers in a ratio of 3.4:1 than when either feedstuff was fed individually at levels comparable to those fed in the combination. Digestibility of dry matter was higher when the silage and cottonseed meal were fed in a ratio of 7.7:1 than when they were fed in the 3.4:1 ratio. These workers felt that these changes could be partially explained by the extent of maceration of the silage in the different rations. Nitrogen and ether extract digestibilities were comparable whether the corn silage and cottonseed meal were fed individually or in combination. Nitrogen-free extract digestibility of both feeds increased, and silage fiber digestibility decreased when the feeds were combined.

Hope et al. (17) noted that total digestible nutrients required for the production of 100 lb. of 4% milk increased as the grain mix was replaced with increasing amounts of finely ground, dehydrated grass-legume forage. These mixtures were fed with grass-legume silage and good, chopped alfalfa hay. They also found that corn meal digestibility was not materially different when fed separately or in combination with silage.

From the results of a trial with Holstein heifers, Mead and Goss (33) concluded that no significant differences existed in the digestibilities of rations consisting of all-concentrate and of concentrate plus 14.8% sulfite wood pulp. However, small differences of from 3 to 9% in digestibility seemed to favor the all-concentrate ration, except in the case of crude fiber which was 15% more digestible in the concentrate-pulp ration than in the all-concentrate ration. A lower digestibility of fiber was the only result of fine grinding of the all-concentrate ration.

Swift et al. (42) observed that the addition of oat straw to a basal ration of mixed hay, corn meal, and linseed oil meal decreased the digestibility of all nutrients from 8 to 12% at the maximum feeding level of 222 g. per day. The addition of starch at the rate of 72 g. per day lowered the digestibility of protein 3% and that of fiber 5%. The digestibilities of other nutrients were relatively unchanged. When corn sugar was added at levels of 150 and 75 g. per day, protein and fiber digestibilities were decreased more than when the starch was added to the basal ration. Casein, added at the rate of 116 g. per day, increased protein digestibility over that of the basal ration by 9.5%; ether extract digestibility was raised 2%, while the digestibility of crude fiber and of nitrogen-free extract was decreased 3% and 2%, respectively.

Protein digestibility was increased 7% over that of the basal ration when urea was added at the rate of 8.8 g. per day. The addition of 34 g. of corn oil per day increased the digestibility of all the nutrients; when 68 g. were added per day, however, the digestibilities of all nutrients except ether extract were decreased.

Watson and associates (51), using Shorthorn steers, found no significant associative effect between barley and oats, and little in a barley-oats-oil cake ration. When oil cake, barley, and oats were fed separately with a hay mixture containing clover, alfalfa, and timothy hays, neither oil cake nor barley underwent any significant change in digestibility. Feeding oats with this hay resulted in a decrease of 5% in the digestibilities of dry matter, organic matter, and total carbohydrates; the total digestible nutrient value of the oats fed in combination with the mixed hay also was lower by 5% than when oats made up the entire ration. When all the feeds were mixed, and fed with the hay, all nutrients were slightly lower in digestibility than when the grains were fed alone, but the decreases were not considered significant.

Watson _et al_. (53) found no associative effect among wheat bran, gluten feed, and soybean oil meal when fed individually with alfalfa-clover hay, or when mixed in equal parts and added to the hay.

Oat hulls were more digestible when fed as the sole ingredient of the ration than when they were included in mixtures with hay in ratios of hay to oat hulls at 1:1 and 5:3. Ether extract digestibility was unaffected, but the digestibility of nitrogen was higher. This held true, also, when oat hulls were added to corn silage and mangels.

Several other feeds were fed in combination to compare their digestibilities when combined with another feed and when fed as the only feed in a ration for steers. Mangels were added to hay; oat straw was added to hay and corn silage, and hay was added to silage. No significant difference in the digestibilities of the mangels of the first combination, of the oat straw of the second combination, or of the hay of the third combination was noted.

When hay was added to mangels---just the reverse of the first trial mentioned above---the digestibility of the nitrogen of the hay was lower than when hay was fed separately.

According to Watkins (45), digestion coefficients for dry matter, organic matter, nitrogen, and ether extract of wheat straw increased when cottonseed meal was combined with the straw in rations for steers. The digestibilities of fiber and nitrogen-free extract remained the same in the combination as when wheat straw was fed separately.

Woll (59) quoted Kellner as follows: "When only two experiments are made, one with hay and the other with hay and wheat bran, there is danger that the coefficients of digestibility obtained by the most careful work may vary from the actual by $\pm$ 9% in the case of crude protein, $\pm$ 6.4% with the nitrogen-free extract, $\pm$ 19.6% with the crude fat, $\pm$ 38.5% with the crude fiber. . . . . Weight can be only given to the averages of many experiments. . . . ." By this statement, Kellner warned against drawing conclusions on digestibility data from the results of only one or a few comparisons between feeds under only one set of conditions.

Armsby (1) concluded that differences in digestibilities of feeds obtained from trials with two or more feeds in a ration might be interpreted as changes in digestibility of the hay or other base; as changes in the added feeds' digestibility, or as changes in the digestibility of the base and the added feeds. If no apparent differences occur, constant digestibility of all feeds in the ration may be considered, or it may be concluded that changes in the digestibility of all the feeds occurred. According to Armsby, the truth is probably between constant digestibility of all feeds and the loss of some digestibility from all or several of the feeds in the ration.

As quoted by Watson (50), Mertins said that for practical calculation of mixed rations, simple addition of the values for individual components of the ration is satisfactory. His conclusion was reached after he made various combinations of the following feeds: clover silage, hay, straw, potato silage, and a concentrate mix of equal parts soybean oil meal, earth nut cake meal, sunflower cake meal, and wheat bran.

The effect of the plane of nutrition on the digestibility of feeds has been studied, and has been found to vary with different feeds.

When feeding alfalfa hay alone to steers, Watson et al. (46) found that the plane of nutrition had no effect on hay digestibility until a level of 9.0 kg. per day was reached. When silage was added to hay or fed alone, its digestibility decreased as the level of feeding was increased (49). When mangels were fed with hay (48), their digestibility was not significantly affected by the plane of nutrition.

Increasing the barley in a barley-hay ration (57) decreased digestibility of the barley by 7-19%.

When hay and barley were fed to steers at the rates of 1.0, 2.0, 3.25, 4.5, and 5.0 kg. each, per day (47), the barley nitrogen and nitrogen-free extract digestibilities dropped 5% and 1.5% respectively as the amount of feed was increased. Digestibilities of the other nutrients of the barley were not significantly affected.

When oats were added to 3.0 kg. of clover-grass hay in 1.0 through 4.6 kg. amounts and fed to Shorthorn steers (58), the digestibility of the oats decreased about 5% at the highest level of feeding.

In other work (56), it was noted that the digestibility of linseed oil meal nutrients except nitrogen and ether extract dropped from 2 to 3% when timothy-legume hay was fed with linseed oil meal in ratios of 3:1 through 3:5. The drop in digestibility was compared to the feeding of linseed oil meal as the only constituent of the ration.

Mumford et al. (35) observed that the digestibility of dry matter, carbohydrate, protein, and fat increased as the ratio of clover hay to ground corn was changed from 1:1 to 1:5 in steer rations. Substitution of one part of linseed oil meal for an equal amount of corn in the 1:5 ratio as listed above caused a greater increase in all digestion coefficients with that of protein being the greatest. The authors concluded that the observed differences in the rations studied were caused by the quantity of fiber present in each case.

Armsby (1) concluded that carbohydrate digestion is lessened in rations containing excessive carbohydrates because as the surplus simple carbohydrates are being digested, those that are more complex are passed through the digestive tract and excreted.

Ewing and Wells (11) indicate that starch may push fiber through the digestive tract because of the laxative effect of the starch. Fiber may also undergo incomplete digestion because of a lack of amylytic enzymes.

According to Armsby (1), protein counteracts the action of excess carbohydrates by causing multiplication and increased activity of bacteria so that they can ferment more carbohydrates. The addition of protein will raise fiber digestibility, particularly if protein is low. The addition of non-protein nitrogen as plant extracts will decrease protein digestibility and digestibility of excess carbohydrates.

Research workers have long desired a simpler method for determining digestion coefficients than the usual time-consuming, expensive total collection method.

Advantages of proposed indicator methods are that they eliminate the necessity for total collection of the feces, allow for trials to be conducted in regular stalls, and effect a saving of labor, time, and expense (24).

In order for a substance to be of value as an indicator in digestibility studies, it must be completely indigestible and be readily mixed thoroughly with the ingesta and the feces (38).

The use of an indicator in digestion trials involves the use of ratios of the indicator to a given nutrient in the feed and feces. The following formula was given by Kane, Jacobson, and Moore (22):

Digestion coefficient = 100 minus

$$100 \left[\frac{(\%\text{ inert material in feed})}{(\%\text{ inert material in feces})} \times \frac{(\%\text{ nutrient in feces})}{(\%\text{ nutrient in feed})} \right]$$

An indicator-ratio technique using chromium oxide was first proposed by Edin in 1918. Other substances have been tried, and for the most part, have been discarded in favor of chromium oxide.

Edin's (9) method was to make up a wheat meal macaroni containing 15% chromium oxide and mix 100 g. of this material with the total daily ration for a cow. His original method for determining chromium oxide in the feces has been greatly modified for simplicity.

Chromium oxide as an indicator has been used successfully with humans (18, 28, 44), steers (4, 32), goats (7), sheep (3, 8, 40), horses (37, 40), swine (3, 30), rats (39), and dairy cattle (7, 9, 15, 16, 20, 21, 22, 24, 31, 36, 38, 44).

Hamilton et al. (19) found the use of chromium oxide with sheep and steers to be unreliable for short collection periods of a day or less and of doubtful advantage for collection periods of three or more days.

Woolfolk (60) believed chromium oxide to be an unsatisfactory reference substance because of the variation in fecal recovery. He obtained an average recovery of chromium oxide of 99.63% from calves and 97.11% from sheep. These disadvantages have been disputed by other workers, however (4, 7, 9, 15, 16, 18, 20, 21, 24, 27, 28, 31, 41, 43).

In an experiment to determine the presence, if any, of diurnal variation in the excretion of chromium oxide, Kane, Jacobson, and Moore (24), using three cows, found a definite variation in percentage of chromium oxide excreted at different hours of the day. They observed a drop in the per cent excreted from 9 a.m. to 9 p.m; then a rise from 9 p.m. to 9 a.m. The per cent of chromium oxide excreted averaged very close to 100 when sampling was done between 4 and 6 a.m. and 1 and 3 p.m. Sampling between 10 and 12 a.m. and 2 and 4 p.m. proved equally valid. In later work with grazing animals (21), they recommended collections from 4 to 6 a.m., 8 to 10 a.m., 1 to 3 p.m., and 7 to 9 p.m. Other work has shown that proper sampling in the morning and afternoon offsets the effect of the diurnal variation in chromium oxide excretion rate (4, 15, 16, 18, 21, 24, 28, 41).

When comparing total collection and the use of chromium oxide simultaneously, Kane, Jacobson, and Moore (22) found no difference in the digestion coefficients derived from either method. Chromium oxide was fed at the rate of 15 g. per day in 100 g. of chromium oxide bread, and 99.3 to 100.4% chromium oxide was recovered in the feces.

In another study by Kane et al. (20), comparisons of total collection, total collection with chromium oxide, and grab sampling using chromium oxide were made. Grab samples were taken once in the forenoon and once in the afternoon for three days. Each sample was analyzed separately. The methods utilizing chromium oxide compared favorably with total collection.

Mahaffey et al. (32) found the lowest average concentration of chromium oxide in feces to be 0.28% at 6 a.m. and the highest concentration to be 0.37% at 6 p.m. when steers were fed on four roughages with four feeding schedules, and four forms of chromium oxide. In these trials, total fecal collections were made at two-hour intervals for the last three days of a seven-day period during which the feed intake was stabilized. The widest range in chromium concentration occurred when the steers were fed six times daily; the narrowest range occurred when they were fed once a day.

When chromium oxide was given in a pure form or dried with collodion, the range of fecal concentration was smaller than when chromium oxide was fed as a gelatin suspension or as a baked flour paste given with the grain.

Irwin and Crampton (18) found no statistical difference in digestion coefficients when chromium oxide was fed once daily to humans or when it was fed at each meal.

Crampton and Lloyd (8), working with sheep, obtained comparable results when they fed chromium oxide as a mix with the concentrate in a concentrate-hay ration either once or twice daily. Pelleting the chromium oxide with grain proved unsatisfactory.

Brannon, Reid, and Miller (4) fed 5 g. of chromium oxide by capsule once daily to steers; collected feces samples at 6 a.m. and at 4 p.m. for not less than four days; and obtained valid results when this method was compared with total collection.

Smith and Reid (41) found that once a day feeding of chromium oxide was sufficient when the feces were collected at 6 a.m. and at 4 p.m. The 24-hour recovery rate under these conditions was 100.58% ± 0.87%, although individual collection times yielded from 65% to 141% chromium oxide in the feces. It was concluded that the time and mode of chromium oxide administration should be determined by the information desired, the amount of control of the animals, and by the preference of the worker for either capsule administration or the use of chromium oxide bread.

Reid (38) noted that when capsules are used once daily, great care must be taken to insure complete ingestion of the capsule by the animal, and sampling must be properly timed in order to obtain an average 100% excretion for the 24 hour period.

In grazing studies with cows, Hardison and Engel (15) found the use of 10 g. capsules once a day to be satisfactory.

Thomason (43) found the use of capsules for chromium oxide administration to be laborious and prone to give unreliable results. He used chromium oxide bread ground and mixed with the concentrate in digestibility studies with cows and concluded that it was a satisfactory indicator.

Hardison and Engel (15), Hardison and Reid (16), Kane *et al.* (21), Brannon, Reid, and Miller (4), Smith and Reid (41), McCullough (31), Noller, Hill, and Lundquist (36), Brundage, Sweetman, and Bula (5), and Lassiter *et al.* (29) used a plant chromogen-chromium oxide technique for determining dry matter intake and digestibility of dry matter for grazing cows and found the method reliable. In these studies the naturally-occurring plant chromogen was used as an indicator for indigestibility of the forage, and chromium oxide was fed to obtain a measure of fecal dry matter per unit of time.

EXPERIMENTAL

This experiment was conducted in order to test the effect of various combinations of hay, silage, and grain on the digestibility of the nutrients of the rations and to observe the practicability of the chromium oxide indicator technique.

Five digestion trials were conducted with five open Guernsey cows using the chromium oxide indicator technique. The cows were kept in stanchions in the Oklahoma A. and M. College dairy barn throughout the experiment, and received no exercise except when walking to the scales for weighing. Water was available at all times in individual drinking cups, and individual feeding was made possible by the use of box compartments in the manger with hinged feeding gates next to the feed alley. Feed was offered at 8 a.m. and at 3 p.m. daily. The cows were weighed each Friday at 4 p.m., and three consecutive daily weights were taken at the beginning and at the end of the experiment.

During trial I, an all-alfalfa ration was fed. Sorghum silage was added to the ration in trial II so as to replace part of the dry matter of trial I for three of the cows and add to the dry matter for two of the cows. In all trials, roughage was fed on a dry matter basis.

Grain was added to the ration in trials III, IV, and V in amounts of 3.0, 6.0, and 9.0 lb., respectively.

The hay varied in quality during the experiment. That for trial I was quite green and leafy, but the hay for trial II was less leafy and slightly stemmy. The hay fed in trial III was quite stemmy and badly shattered. Consumption of this hay dropped sharply when compared to hay consumption in trials I and II. During trials IV and V, the hay was again of good quality. That fed in trial V was the best of any fed during the experiment.

Silage was of uniformly good quality throughout the experiment, and the grain used consisted of a mixture of 800 lb. of milo, 600 lb. of oats, 600 lb. of bran, 20 lb. of trace-mineralized salt, 20 lb. of ground limestone, and 20 lb. of steamed bonemeal.

Hay for separate trials was set aside and sampled by drilling cores from all bales selected. The cores were mixed thoroughly, sampled, ground, re-sampled, and placed in tight jars until analyses were made.

Silage was sampled periodically throughout each trial. Immediately after removal of the samples from the silo, they were weighed, dried, reweighed, ground, and stored in jars.

Sufficient grain was sacked before each trial to last through the trial. Samples were taken as the grain came from the bin; these were compounded and stored for analysis.

All feed samples were ground such that they would pass through the medium screen of the Wiley mill.

It was intended that the cows should completely consume their feed, but some refusals during the collection periods occurred, and these were weighed back and composited for individual cows for analysis at the end of each trial.

During trials I and II, a mineral mix consisting of one part trace-mineralized salt, one part ground limestone, and one part steamed bonemeal was fed once daily at the rates recommended by Morrison (35). When grain feeding began in trial III, this mineral feeding was discontinued.

The minerals in trials I and II and the grain in trials III, IV, and V were fed before the roughage to insure complete ingestion of the chromium oxide which was mixed with the minerals or grain in the morning only. Approximately 15 g. of chromium oxide were fed per cow per day. This was fed as a chromium oxide bread which was prepared by making a dough of 15.0 g. chromium oxide, 85.0 g. of non-rising flour, and water. After the dough was thoroughly mixed and dried at 100-200° C., it was ground so as to pass through the coarse screen of a Wiley mill. Separate batches were baked for trials I and II, and a third batch was baked for trials III, IV, and V.

Each trial was divided into a 10-day standardization period during which the cows had a constant intake, a 10-day preliminary period during which the feed intake remained constant and chromium oxide was added to the ration, and a 5-day collection period. Usually more than 20 days elapsed between the end of one collection period and the beginning of the next because of difficulty in getting the cows on a constant intake.

During the collection periods, feces were collected by taking four equal grab samples per day from each cow. Times of collection were between 6 and 8 a.m., 10 a.m. and 12 noon, 2 and 4 p.m., and 7 and 9 p.m. As the grab samples were collected, they were composited in half-gallon jars and stored under refrigeration at 37° F. with thymol crystals added for additional protection. At the end of each trial, the feces for each cow were mixed, weighed, and dried at 100° C., reweighed, ground so as to pass through the medium screen of the Wiley mill, and stored in tight jars.

Proximate analyses were run on all feed and feces samples according to the official methods of A. O. A. C. (2). Dry matter of the hay and silage was determined immediately after sampling so that these values could be used in compounding the rations. Duplicate samples were analyzed for all nutrients, and the averages of the duplicates were used in calculating digestion coefficients.

The chromium oxide content of the feces and the chromium oxide bread was determined according to the method outlined by Schurch, Lloyd, and Crampton (39).

A standard curve for chromium oxide readings was established with dilutions of duplicate stock solutions prepared in the following manner: One gram of chromium oxide for each solution was fused with sodium peroxide, and the fused material was immersed in cold water for 10 minutes. The crucibles were then thoroughly washed with hot water, and the material was allowed to stand for 30 minutes in 600 ml. beakers and filtered. The filtrate was made up to one liter; aliquots of 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 ml. were placed in separate 500 ml. volumetric flasks and made up to volume. The per cent light transmission was measured in an Evelyn photoelectric colorimeter at 440 mμ, and distilled water was used as a blank.

RESULTS AND DISCUSSION

Digestion coefficients for all nutrients of the total rations are compiled in Table 1. In Table 2 are summarized the average digestion coefficients of individual feeds. Tables 3 through 7 show the digestible protein and total digestible nutrients furnished and required for maintenance with the calculated nutritive ratios, and Table 8 shows total digestible nutrients utilized per pound of bodyweight gain. Feed and chromium oxide intake for the collection periods, feed and feces analyses, total digestible nutrients of the rations, and body weights of the cows are presented in Appendix Tables I through X.

As shown in Table 1, as the plane of nutrition increased from trials I to IV, a general decrease in the digestibilities of all nutrients except ether extract, occurred with few exceptions. In trial V, although the plane of nutrition continued to increase for three cows, dry matter digestibility in the case of two cows increased over that of trial IV. Figures for one of these cows showed that digestibility of nitrogen-free extract was also greater in trial V. In all cases the digestibilities of nitrogen-free extract, of fiber, and of nitrogen were more variable than those of the other nutrients.

The addition of dry matter as silage in trial II appeared to increase the digestibility of all nutrients except fiber and ether extract from 4.0 to 5.75% over that observed with the rations in which silage replaced one half of the dry matter of the hay. Ether extract was decreased in

Table 1

DIGESTION COEFFICIENTS OF NUTRIENTS OF ALL RATIONS

Cow No.	Trial No.	D.M.	Nitrogen	E.E.	Fiber	N.F.E.
1305	1	59.49	63.14	- 6.86	44.66	67.72
	2	68.01	74.98	42.32	58.22	76.72
	3	64.68	71.70	55.96	50.83	71.21
	4	59.58	64.29	67.69	47.61	70.24
	5	61.73	65.06	65.69	36.34	73.50
1321	1	68.56	74.73	29.19	57.14	75.46
	2	62.86	73.12	38.83	54.84	72.80
	3	59.36	66.99	57.14	47.65	67.44
	4	64.65	68.36	61.50	56.64	70.69
	5	67.01	61.92	61.30	37.16	72.02
421	1	71.23	76.25	33.89	59.00	77.00
	2	60.80	67.07	47.87	57.61	67.70
	3	63.65	64.49	42.32	52.64	69.77
	4	66.98	71.24	70.22	58.04	75.02
	5	60.09	63.89	62.71	46.80	68.91
1404	1	65.56	71.25	11.61	52.77	73.17
	2	53.78	63.01	39.90	49.38	64.27
	3	66.59	70.69	70.22	62.08	74.52
	4	61.78	67.50	59.31	55.46	72.55
	5	63.82	61.24	62.26	46.50	69.82
1405	1	74.15	79.47	41.34	59.63	79.38
	2	68.92	72.50	56.03	62.01	75.04
	3	63.72	66.35	56.88	48.00	73.02
	4	62.78	65.94	63.60	50.28	71.58
	5	62.94	65.22	60.59	36.05	74.39

digestibility, while the digestion of fiber was unchanged. A study of the rations which were higher in digestibility revealed that they were somewhat better balanced than the others.

When the associative effects of adding grain in varying amounts to various basal rations were studied, digestibility of the added grain was determined by difference. In this method, it was assumed that the digestibility of the basal ration remained constant whether it was fed alone or in combination. The digestible nutrients for the total ration were calculated; the digestible nutrients of the basal ration were subtracted from the total, and the remainder was allotted to the added feed. In trial II, digestion coefficients for the silage were also computed by difference.

The calculations resulted in some extremely large and some negative coefficients for the added grain in some instances. It is felt that these unusual values were due largely to errors in the method of determining digestibility by difference, although some error also may have been introduced in the determination of digestion coefficients of the basal rations.

The associative effects on grain digestibility were studied in several ways, the first being to study differences among the three levels of grain when the roughage was considered to be the basal ration. Averages of these digestion coefficients are summarized in Table 2. Although there were variations between individual cows, averages indicated a decrease in digestibility as more grain was added to the basal ration. Since digestion coefficients for fiber varied from negative values to values over 100%, they had little meaning.

When the basal ration was assumed to consist of roughage plus

Table 2

AVERAGE DIGESTION COEFFICIENTS OF FEEDS

Ration	D.M.	Nitrogen	E. E.	Fiber	N.F.E.
Hay	70.05	75.63	29.73	57.31	76.38
Silage	51.31	52.68	57.46	52.57	65.46
Grain (basal--roughage)					
3 lb. grain added	68.72	61.82	96.00	neg.	72.21
6 lb. grain added	64.12	63.82	85.48	60.00	73.01
9 lb. grain added	63.53	57.44	77.96	neg.	72.10
Grain (basal--roughage) plus 3 lb. grain)					
3 lb. grain added	62.70	64.51	92.58	76.47	75.04
6 lb. grain added	62.51	54.46	73.43	neg.	72.51
Grain (basal--roughage plus 6 lb. grain)					
3 lb. grain added	63.00	43.75	54.25	neg.	70.14

3.0 lb. of the grain mix, and 3.0 lb. and 6.0 lb. of the grain were added, all nutrients were lower in digestibility at the higher level of grain feeding. This was true for the majority of the individual calculations as well as for the averages.

The last calculation made was to include 6.0 lb. of grain in the basal ration with the roughage and add 3.0 lb. of grain. For all nutrients except dry matter, lower average digestion coefficients were calculated in this method than in the others.

The two sets of grain nutrient digestion coefficients which most nearly approached expected values were actually based on the same ration but were calculated in two different ways: first, by considering 6.0 lb. of grain as added to a basal ration of roughage, and second, 3.0 lb. of grain as added to a basal ration of roughage and 3.0 lb. of grain.

Using arithmetic averages of values obtained with five cows to express the digestibility of the grain seemed justified. In the case of 12 of 26 coefficients, the median was higher than the average, and in three of these, the coefficient was higher than might normally be expected. Two of the higher averages might be considered too high, but in one case, the accompanying median was also excessively high.

The digestible protein and total digestible nutrients furnished, maintenance requirements according to Morrison's allowances, and the corresponding nutritive ratios for each collection period are presented in Tables 3 through 7.

The values obtained by figuring total digestible nutrients per pound of bodyweight gain during each trial are given in Table 8. These were computed by subtracting Morrison's recommended maintenance requirements from the total digestible nutrients fed and dividing the remainder

Table 3

DIGESTIBLE PROTEIN AND TOTAL DIGESTIBLE NUTRIENTS FURNISHED AND REQUIRED FOR MAINTENANCE, TOTAL DIGESTIBLE NUTRIENTS AVAILABLE FOR WEIGHT GAIN, AND NUTRITIVE RATIOS DURING COLLECTION PERIODS, COW 1305.

Trial No.	Category	D.P. lb.	T.D.N. lb.	Nutritive Ratio
1	Furnished	10.00	47.5	1:3.75
	Required	2.70	32.5	
	Am'ts. avail. for wt. gain	7.30	15.0	
2	Furnished	12.58	63.0	1:4.01
	Required	2.80	34.5	
	Am'ts. avail. for wt. gain	9.78	28.5	
3	Furnished	6.81	38.5	1:4.65
	Required	2.85	35.0	
	Am'ts. avail. for wt. gain	3.96	3.5	
4	Furnished	6.49	52.4	1:7.07
	Required	2.95	36.0	
	Am'ts. avail. for wt. gain	3.54	16.4	
5	Furnished	7.00	49.6	1:6.08
	Required	3.00	36.5	
	Am'ts. avail. for wt. gain	4.00	13.1	

Table 4

DIGESTIBLE PROTEIN AND TOTAL DIGESTIBLE NUTRIENTS FURNISHED AND REQUIRED FOR MAINTENANCE, TOTAL DIGESTIBLE NUTRIENTS AVAILABLE FOR WEIGHT GAIN, AND NUTRITIVE RATIOS DURING COLLECTION PERIODS, COW 1321.

Trial No.	Category	D.P. lb.	T.D.N. lb.	Nutritive Ratio
1	Furnished	11.63	55.2	1:3.75
	Required	2.95	36.0	
	Am'ts. avail. for wt. gain	8.68	19.2	
2	Furnished	15.07	70.4	1:3.67
	Required	3.10	38.0	
	Am'ts. avail. for wt. gain	11.97	32.4	
3	Furnished	6.35	39.7	1:5.26
	Required	3.20	38.5	
	Am'ts. avail. for wt. gain	3.15	1.2	
4	Furnished	7.52	47.1	1:5.26
	Required	3.25	39.5	
	Am'ts. avail. for wt. gain	4.27	7.6	
5	Furnished	7.37	53.6	1:6.27
	Required	3.30	40.0	
	Am'ts. avail. for wt. gain	4.07	13.6	

Table 5

DIGESTIBLE PROTEIN AND TOTAL DIGESTIBLE NUTRIENTS FURNISHED AND REQUIRED FOR MAINTENANCE, TOTAL DIGESTIBLE NUTRIENTS AVAILABLE FOR WEIGHT GAIN, AND NUTRITIVE RATIOS DURING COLLECTION PERIODS, COW 421.

Trial No.	Category	D.P. lb.	T.D.N. lb.	Nutritive Ratio
1	Furnished	11.85	56.7	1:3.78
	Required	2.80	34.5	
	Am'ts. avail. for wt. gain	9.05	22.2	
2	Furnished	8.21	47.5	1:4.78
	Required	2.95	36.0	
	Am'ts. avail. for wt. gain	5.26	11.5	
3	Furnished	6.71	43.7	1:5.52
	Required	3.10	38.0	
	Am'ts. avail. for wt. gain	3.61	5.7	
4	Furnished	7.59	49.6	1:5.54
	Required	3.15	38.5	
	Am'ts. avail. for wt. gain	4.44	11.1	
5	Furnished	7.31	51.5	1:6.05
	Required	3.25	39.5	
	Am'ts. avail. for wt. gain	4.06	12.0	

Table 6

DIGESTIBLE PROTEIN AND TOTAL DIGESTIBLE NUTRIENTS FURNISHED AND REQUIRED FOR MAINTENANCE, TOTAL DIGESTIBLE NUTRIENTS AVAILABLE FOR WEIGHT GAIN, AND NUTRITIVE RATIOS DURING COLLECTION PERIODS, COW 1404.

Trial No.	Category	D.P. lb.	T.D.N. lb.	Nutritive Ratio
1	Furnished	9.33	43.8	1:3.69
	Required	2.75	33.5	
	Am'ts. avail. for wt. gain	6.58	10.3	
2	Furnished	6.46	36.8	1:4.69
	Required	2.80	34.5	
	Am'ts. Avail. for wt. gain	3.66	2.3	
3	Furnished	7.22	48.5	1:5.71
	Required	3.00	36.5	
	Am'ts. avail. for wt. gain	4.22	12.0	
4	Furnished	7.22	48.4	1:5.70
	Required	3.00	36.5	
	Am'ts. avail. for wt. gain	4.22	11.9	
5	Furnished	7.11	52.7	1:6.41
	Required	3.05	37.0	
	Am'ts. avail. for wt. gain	4.06	15.3	

Table 7

DIGESTIBLE PROTEIN AND TOTAL DIGESTIBLE NUTRIENTS FURNISHED AND REQUIRED FOR MAINTENANCE, TOTAL DIGESTIBLE NUTRIENTS AVAILABLE FOR WEIGHT GAIN, AND NUTRITIVE RATIOS DURING COLLECTION PERIODS, COW 1405.

Trial No.	Category	D.P. lb.	T.D.N. lb.	Nutritive Ratio
1	Furnished	12.35	58.5	1:3.74
	Required	2.80	34.5	
	Am'ts. avail. for wt. gain	9.55	24.0	
2	Furnished	8.74	51.8	1:4.93
	Required	2.95	36.0	
	Am'ts. avail. for wt. gain	5.79	15.8	
3	Furnished	5.15	32.8	1:5.36
	Required	2.95	36.0	
	Am'ts. avail. for wt. gain	2.20	- 3.2	
4	Furnished	6.66	53.2	1:6.98
	Required	3.20	39.0	
	Am'ts. avail. for wt. gain	3.46	14.2	
5	Furnished	7.11	50.4	1:6.09
	Required	3.05	37.0	
	Am'ts. avail. for wt. gain	4.06	13.4	

Table 8

TOTAL DIGESTIBLE NUTRIENTS PER POUND OF BODYWEIGHT GAIN

DURING EACH TRIAL

Cow No.	Trial No.	Initial Wt. lb.	Wt. Gain lb.	T.D.N. Fed lb.	Maint. T.D.N. lb.	Wt. Gain T.D.N. lb.	T.D.N./# of Gain lb.
1305	1	825	- 8	254.4	167.5	86.9	.....
	2	884	- 9	329.1	177.5	151.6	.....
	3	892	-21	169.4	151.2	18.2	.....
	4	901	9	228.2	144.0	84.2	9.36
	5	910	29	209.8	151.2	58.6	2.02
1321	1	880	36	276.1	177.5	98.6	2.74
	2	963	3	353.2	192.5	160.7	53.57
	3	1007	-31	188.0	165.9	22.1	.....
	4	992	9	206.5	158.0	48.5	5.39
	5	1001	44	222.5	165.9	56.6	1.29
421	1	835	36	283.8	167.5	116.3	3.23
	2	886	24	237.5	177.5	60.0	2.50
	3	944	2	193.1	159.6	33.5	16.75
	4	977	12	215.5	155.0	60.5	5.04
	5	989	25	214.3	163.8	50.5	2.02
1404	1	817	11	218.5	165.8	52.7	4.79
	2	865	10	183.6	175.0	8.6	.86
	3	892	23	203.8	144.0	59.8	2.60
	4	918	8	212.4	146.6	65.8	8.23
	5	926	35	219.1	155.4	63.7	1.82
1405	1	844	10	292.6	172.5	120.1	12.01
	2	891	5	259.8	180.0	79.8	15.96
	3	900	-21	131.4	151.2	-19.8	.....
	4	929	18	231.4	148.0	83.4	4.63
	5	947	9	209.9	159.6	50.3	5.59

by the weight gain. The fact that some cows seemed to lose weight even though more digestible protein and total digestible nutrients were available than were required for maintenance might be explained in part by the variation in weekly body weights. Also, full utilization of the feed may not have been made by some of the cows due to narrow nutritive ratios. Because only single weekly body weights were taken, and such variation in total digestible nutrients per pound of body weight gain were observed, these values were not considered satisfactory for evaluating the rations.

Preliminary work with chromium oxide indicated that when it was administered by capsule to cows, erratic recovery rates were encountered. It was also found that mixing pure chromium oxide with the feed was not feasible because its heavier weight caused it to settle out of the feed and adhere to the container. For this experiment, the chromium oxide was, therefore, mixed with flour and administered as a ground bread. The preparation and grinding of the bread and mixing it with the feed, the determination of chromium oxide in the feces and bread, the calculation of the per cent chromium oxide fed, and the establishment of a standard curve for chromium oxide colorimeter readings were laborious and time-consuming steps. The four trips to the barn at odd hours for sampling were factors of additional work. There seemed to be more possibility of introducing error during all the steps of the chromium oxide techinque than in the case of the total collection method.

Digestion coefficients for the hay obtained by the use of the chromium oxide technique were reasonably close to Morrison's values, however, it is possible that some of the unusual coefficients of the rations containing other feeds were due to errors in this technique.

Undoubtedly, the use of the chromium oxide method in grazing trials is worthwhile because of the inability to measure forage intake directly. However, it is felt that if a suitable apparatus for separating and collecting feces and urine were used, total collection would be a better method of conducting digestion trials when the cows are confined.

SUMMARY AND CONCLUSIONS

The digestibilities of rations composed of various quantities of roughage and grain were studied using the chromium oxide indicator technique.

Five digestion trials using five open Guernsey cows were conducted using rations consisting of all-alfalfa hay, alfalfa hay and sorghum silage, and alfalfa hay and sorghum silage plus 3.0, 6.0, and 9.0 lb. of grain.

As the plane of nutrition increased from trials I to IV, a general decrease in the digestibilities of all nutrients except ether extract occurred with few exceptions. In trial V, although the plane of nutrition was higher than in trial IV in the case of three cows, there were higher digestibilities of nitrogen-free extract in one instance and of dry matter in two cases. In all trials, digestion coefficients of nitrogen-free extract, of fiber, and of nitrogen were quite variable.

The addition of dry matter to a ration of alfalfa hay in the form of silage caused slight increases in digestion of all nutrients except ether extract and fiber when compared to a ration in which one half of the dry matter of the ration was replaced by silage.

The digestibility of grain added in successively larger amounts to a basal ration of hay and silage or to a basal ration including roughage and 3.0 lb. of grain appeared to decrease as larger amounts of grain were added. Calculations for some grain nutrients were quite variable.

Digestion coefficients were also calculated for 3.0 lb. of grain added to a basal ration of roughage and 6.0 lb. of grain. The combinations which yielded the most reasonable coefficients were the addition of 6.0 lb. of grain to an all-roughage basal ration and the addition of 3.0 lb. of grain to a basal ration which contained roughage and 3.0 lb. of grain.

Digestion coefficients of the alfalfa hay determined by the use of the chromium oxide method compared favorably with those reported by Morrison for alfalfa hay of the same general quality. Errors in the method may have been responsible for some of the unexpected digestion coefficients in the other rations, however, so there may be some doubt with respect to the value of the method.

From the results obtained in these trials, it could be concluded that digestibility of rations composed of alfalfa hay, sorghum silage, and a grain mix containing milo, oats,and bran decreased as the plane of nutrition increased. The amount of decrease was not predictable. Although a decrease in digestibility of the grain as the larger amounts were added to the basal rations was calculated, it is felt that changes in digestibility of a mixed ration should not all be charged to any one of the feeds in the ration. This is what is done when the digestibility of added feed or feeds is computed by difference and associative effects are studied.

Drawbacks to the use of the chromium oxide method are (1) the work involved in mixing, baking,and grinding the bread, (2) mixing the ground bread with the feed, (3) making four separate trips at odd hours to collect feces grab samples, (4) the analysis of feces and bread for chromium oxide content, (5) establishment of a standard curve for the colorimeter readings, and (6) the possibility of introduction of error in all these steps.

Total collection would appear to be a more satisfactory method of conducting digestion trials from the standpoint of the time and work involved and the possibility of errors in the chromium oxide technique.

LITERATURE CITED

1. Armsby, H. P. The Nutrition of Farm Animals. MacMillan Publ. Co., New York. 1917.

2. Association of Official Agricultural Chemists. Official Methods of Analysis. 7th ed. George Banta Publ. Co., Menasha, Wisc.

3. Barnicoat, C. R. (Cited by Schurch, A. F., Lloyd, L. E., and Crampton, E. W.) J. Nutrition 41: 630. 1950.

4. Brannon, W. F., Reid, J. T., and Miller, J. I. The Influence of Certain Factors Upon the Digestibility and Intake of Pasture Herbage by Beef Steers. J. Animal Sci., 13: 535. 1954.

5. Brundage, A. L., Sweetman, W. J., and Bula, R. J. The Utilization of Smooth Bromegrass (Bromus Inermis) Under Rotational and Strip Grazing Systems of Pasture Management. II. Digestibility-Intake Studies. J. Dairy Sci., 39: 287. 1956.

6. Bull, S. The Principles of Feeding Farm Animals. MacMillan Publ. Co., New York. 1917.

7. Chanda, R., Clapham, Helen M., McNaught, Mary L., and Owen, E. C. The Use of Chromium Sesquioxide to Measure the Digestibility of Carotene by Goats and Cows. J. of Agr. Sci., 41: 179. 1951.

8. Crampton, Earle W., and Lloyd, Lewis E. Studies with Sheep on the Use of Chromic Oxide as an Index of Digestibility of Ruminant Rations. J. Nutrition, 45: 319. 1951.

9. Edin, H., Kihlen, G., and Nordfeldt, S. A Summarized Description of Edin's Indicator Method for the Determination of the Digestibility of Feeds and Feed Mixtures. Ann. Royal Coll. of Sweden, 12: 166. 1944.

10. Ewing, P. V., and Smith, F. H. Digestibility of Corn Silage, Velvetbean Meal, and Alfalfa Hay When Fed Singly and in Combinations. J. Agr. Res., 13: 611. 1918.

11. Ewing, P. V., and Wells, C. A. The Associative Digestibility of Corn Silage, Cottonseed Meal, and Starch in Steer Rations. Ga. Expt. Sta., Bull. 115. 1915.

12. Ewing, P. V., Wells, C. A., and Smith, F. H. The Associative Digestibility of Corn Silage and Cottonseed Meal in Steer Rations. II. The Influences Exerted by Corn Silage and Cottonseed Meal on the Digestion Coefficients of Each Other When Fed in Combination, as Determined by Means of a Fractional Separation of the Feces. Ga. Agr. Exp. Sta., Bull. 125. 1917.

13. Forbes, E. B., Braman, W. W., Kriss, Max, and Swift, R. W. The Metabolizable Energy and Net Energy Values of Corn Meal When Fed Exclusively and in Combination with Alfalfa Hay. J. Agr. Res., 43: 1015. 1931.

14. Forbes, E. B., and Swift, R. W. Conditions Affecting the Digestibility and the Metabolizable Energy of Feeds for Cattle. Penna. Agr. Expt. Sta., Bull. 452. 1943.

15. Hardison, W. A., Engel, R. W., Graf, G. C., and Linkous, W. N. Dry Matter Intake and Digestibility Studies with Grazing Dairy Animals—A Progress Report. J. Dairy Sci., 37: 665. 1954. (Abstr.).

16. Hardison, W. A., and Reid, J. T. Use of Indicators in the Measurement of the Dry Matter Intake of Grazing Animals. J. Nutrition, 51: 35. 1953.

17. Hope, E. B., Erb, R. E., Blosser, T. H., Ashworth, U. S., and Shaw, A. O. The Use of Dehydrated Forages in Dairy Cattle Rations. I. Grain Substitution with Finely Ground Material. J. Dairy Sci., 33: 306. 1950.

18. Irwin, Mary I., and Crampton, Earle W. The Use of Chromic Oxide as an Index Material in Digestion Trials with Human Subjects. J. Nutrition, 43: 77. 1951.

19. ______. "New Method Tested in Digestibility Trials". Ill. Agr. Expt. Sta., 41st Annual Rep., 119. 1927-28.

20. Kane, E. A., Ely, R. E., Jacobson, W. C., and Moore, L. A. A Comparison of Various Digestion Trial Techniques with Dairy Cattle. J. Dairy Sci., 36: 325. 1953.

21. Kane, E. A., Jacobson, W. C., Ely, R. E., and Moore, L. A. The Estimation of the Dry Matter Consumption of Grazing Animals by Ratio Techniques. J. Dairy Sci., 36: 637. 1953.

22. Kane, E. A., Jacobson, W. C., and Moore, L. A. A Comparison of Techniques Used in Digestibility Studies with Dairy Cattle. J. Nutrition, 41: 583. 1950.

23. Kane, E. A., Jacobson, W. C., and Moore, L. A. Digestibility Studies on Dairy Cattle: A Comparison of the Total Collection Methods; Conventional versus Chromium Oxide and Lignin Techniques. J. Animal Sci., 8: 623. 1949. (Abstr.).

24. Kane, E. A., Jacobson, W. C., and Moore, L. A. Diurnal Variation in the Excretion of Chromium Oxide and Lignin. J. Nutrition, 47: 263. 1952.

25. Kane, E. A., Jacobson, W. C., and Moore, L. A. Use of Chromium Oxide as Indicator of Digestibility. Fed. of Amer. Soc. for Exptl. Biol. Fed. Proc. 9: 362. 1950. (Abstr.).

26. Knott, J. C., Hodgson, R. E., and Ellington, E. V. Methods of Measuring Pasture Yields with Dairy Cattle. Wash. Agr. Expt. Sta., Bull. 295. 1934.

27. Knott, J. C., and Murer, H. K. The Determination of the Apparent Digestibility of Green and Cured Grass by Modified Procedures. J. Agr. Res., 53: 553. 1936.

28. Kreula, M. S. Absorption of Carotene from Carrots in Man and the Use of the Quantitative Chromic Oxide Indicator Method in the Absorption Experiments. Biochem. J., 41: 269. 1947.

29. Lassiter, C. A., Seath, D. M., Woodruff, J. W., Taylor, J. A., and Rust, J. W. Comparative Value of Kentucky Bluegrass, Kentucky 31 Fescue, Orchard Grass, and Bromegrass as Pasture for Milk Cows. II. Effect of Kind of Grass on the Dry Matter and Crude Protein Content and Digestibility and Intake of Dry Matter. J. Dairy Science., 39: 581. 1956.

30. Lloyd, L. E. Unpublished data. (Cited by Crampton, E. W., and Lloyd, L. E.) J. Nutrition, 45: 319. 1951.

31. McCullough, M. E. The Use of Indicator Methods in Measuring the Contribution of Two Forages to the Total Ration of the Dairy Cow. J. Dairy Sci., 36: 445. 1953.

32. Mahaffey, J. C., Miller, W. J., Donker, J. D., and Dalton, H. L. Effect of Certain Factors on the Diurnal Excretion Pattern of Chromic Oxide. J. Dairy Sci., 37: 672. 1954. (Abstr.).

33. Mead, S. W., and Goss, H. Ruminant Digestion Without Roughage. J. Dairy Sci., 18: 163. 1935.

34. Morrison, F. B. Feeds and Feeding. 21st ed. The Morrison Publ. Co., Ithaca, New York. 1948.

35. Mumford, H. W., Grindley, H. S., Hall, L. D., and Emmett, A. D. A Study of the Digestibility of Rations for Steers with Special Reference to the Influence of the Character and the Amount of Feed Consumed. Ill. Agr. Expt. Sta., Bull. 172. 1914.

36. Noller, C. H., Hill, D. L., and Lundquist, N. S. Observations on the Use of the Chromogen Technique in Determining Forage Consumption of Milking Cows. J. Animal Sci., 10: 1072. 1951. (Abstr.).

37. Olsson, N., Kihlen, G., and Cagell, W. (Cited by Schurch, A. F., Lloyd, L. E., and Crampton, E. W.). J. Nutrition, 41: 630. 1950.

38. Reid, J. Thomas. Indicator Methods, Their Potentialities and Limitations. Sixth Grassland Congress. Proc., 2: 1334. 1952.

39. Schurch, A. F., Lloyd, L. E., and Crampton, E. W. The Use of Chromic Oxide as an Index for Determining the Digestibility of a Diet. J. Nutrition, 41. 629. 1950.

40. Skulmowski, J., Szymanski, A., and Wyszinski, T. (Cited by Schurch, A. F., Lloyd, L. E., and Crampton, E. W.) J. Nutrition, 41: 630. 1950.

41. Smith, A. M., and Reid, J. T. Use of Chromic Oxide as an Indicator of Fecal Output for the Purpose of Determining the Intake of Pasture Herbage by Grazing Cows. J. Dairy Sci., 38: 515. 1955.

42. Swift, R. W., Thacker, E. J., Black, A., Bratzler, J. W., and James, W. H. Digestibility of Rations for Ruminants as Affected by Proportions of Nutrients. J. Animal Sci., 6: 432. 1947.

43. Thomason, Eddie L. The Effect of Level of Grain Feeding Upon the Efficiency of Milk Production. Thesis. Oklahoma A. and M. College. 1955.

44. Virtanen, A. I. (Cited by Schurch, A. F., Lloyd, L. E., and Crampton, E. W.). J. Nutrition, 41: 630. 1950.

45. Watkins, W. E. The Digestibility of Cottonseed Meal as a Supplemental Feed for Range Cattle in New Mexico. New Mexico Agr. Expt. Sta., Bull. 178 (Tech.) 1929.

46. Watson, C. J., Muir, G. W., and Davidson, W. M. Digestibility Studies with Ruminants. I. Plane of Nutrition and Digestibility of Hay. Sci. Agr., 15: 476. 1935.

47. Watson, C. J., Woodward, J. C., Davidson. W. M., Muir, G. W., and Robinson, C. H. Digestibility Studies with Ruminants. II. Plane of Nutrition and Digestibility of a Hay-Barley Ration. Sci. Agr., 17: 11. 1936.

48. Watson, C. J., Woodward, J. C., Davidson, W. M., Robinson, C. H., and Muir, G. W. Digestibility Studies with Ruminants. III. Plane of Nutrition and Digestibility of Mangels. Sci. Agr., 18: 586. 1938.

49. Watson, C. J., Woodward, J. C., Davidson, W. M., Robinson, C. H., and Muir, G. W. Digestibility Studies with Ruminants. IV. Plane of Nutrition and Digestibility of Corn Silage. Sci. Agr., 19: 622. 1939.

50. Watson, C. J., Woodward, J. C., Davidson, W. M., Robinson, C. H., and Muir, G. W. Digestibility Studies with Ruminants. V. Associative Digestibility Among Roughages and Succulent Feeds. Sci. Agr. 20: 175. 1939.

51. Watson, C. J., Campbell, J. A., Davidson, W. M., Robinson, C. H., and Muir, G. W. Digestibility Studies with Ruminants. VI. Associative Digestibility of Grains: Barley, Oats, and Oil Cake. Sci. Agr., 20: 238. 1939.

52. Watson, C. J., Campbell, J. A., Davidson, W. M., Robinson, C. H., and Muir, G. W. Digestibility Studies with Ruminants. VIII. Associative Digestibility of Hay and Grains. Sci. Agr., 22: 250. 1941.

53. Watson, C. J., Campbell, J. A., Davidson, W. M., Robinson, C. H., and Muir, G. W. Digestibility Studies with Ruminants. IX. Associative Digestibility of Grains: Wheat Bran, Gluten Feed, and Soybean Oil Meal. Sci. Agr., 22: 561. 1942.

54. Watson, C. J., Kennedy, J. W., Davidson, W. M., Robinson, C. H., and Muir, G. W. Digestibility Studies with Ruminants. X. Relative Associative Effects of the Roughages, Timothy and Alfalfa, with Barley. Sci. Agr., 27: 175. 1947.

55. Watson, C. J., Kennedy, J. W., Davidson, W. M., Robinson, C. H., and Muir, G. W. Digestibility Studies with Ruminants. XI. The Effect of the Nutritive Ratio of a Ration Upon its Digestibility by Cattle. Sci. Agr., 27: 600. 1947.

56. Watson, C. J., Kennedy, J. W., Davidson, W. M., Robinson, C. H., and Muir, G. W. Digestibility Studies with Ruminants. XIII. The Effect of the Plane of Nutrition on the Digestibility of Linseed Oil Meal. Sci. Agr., 29: 263. 1949.

57. Watson, C. J., Kennedy, J. W., Davidson, W. M., Robinson, C. H., and Muir, G. W. Digestibility Studies with Ruminants. XIV. The Effect of the Plane of Nutrition on the Digestibility of Barley. Sci. Agr., 29: 400. 1949.

58. Watson, C. J., Davidson, W. M., Kennedy, J. W., and Sylvestre, P. E. Digestibility Studies with Ruminants. XV. The Effect of the Plane of Nutrition on the Digestibility of Oats in an Oats-Hay Ration. Sci. Agr., 31: 113. 1951.

59. Woll, J. B. Productive Feeding of Farm Animals. Lippincott Co., Philadelphia. 1915.

60. Woolfolk, P. G., Richards, C. R., Kaufmann, R. W., Martin, C. M., and Reid, J. T. A Comparison of Fecal Nitrogen Excretion Rate, Chromium Oxide and "Chromogen(s)" Methods for Evaluating Forages and Roughages. J. Dairy Sci., 33: 385. 1950. (Abstr.).

APPENDIX

APPENDIX

TABLE I

FEED AND CHROMIUM OXIDE INTAKE DURING COLLECTION PERIODS

FOR ALL TRIALS, COW 1305

Trial No.	Feed	Am't. Fed lb.	Dry Matter lb.	Cr_2O_3 Total g.	Cr_2O_3 % of Total Feed	Cr_2O_3 % of D.M.
1	Hay	80.8	75.1	74.4050	0.20	0.22
2	Hay	74.3	68.9			
	Silage	130.2	28.3			
	Total	204.5	97.2	77.6350	0.09	0.18
3	Hay	35.0	32.1			
	Silage	80.0	15.8			
	Grain	15.0	13.3			
	Total	130.0	61.2	77.5905	0.13	0.28
4	Hay	26.5	24.1			
	Silage	83.0	18.9			
	Grain	30.0	26.7			
	Total	139.5	69.7	77.5905	0.12	0.24
5	Hay	20.0	18.0			
	Silage	69.0	18.2			
	Grain	44.6	41.0			
	Total	133.6	77.3	77.5905	0.13	0.22

TABLE II

FEED AND CHROMIUM OXIDE INTAKE DURING COLLECTION PERIODS

FOR ALL TRIALS, COW 1321

Trial No.	Feed	Am't. Fed lb.	Dry Matter lb.	Cr_2O_3 Total g.	Cr_2O_3 % of Total Feed	Cr_2O_3 % of D.M.
1	Hay	95.0	88.2	74.4050	0.17	0.19
2	Hay	94.5	87.6			
	Silage	124.5	27.1			
	Total	219.0	114.7	77.6350	0.08	0.15
3	Hay	30.0	27.5			
	Silage	130.0	25.6			
	Grain	15.0	13.3			
	Total	175.0	66.4	77.5905	0.10	0.26
4	Hay	30.5	27.7			
	Silage	95.5	21.7			
	Grain	30.0	26.7			
	Total	156.0	76.1	77.5905	0.10	0.22
5	Hay	24.5	22.2			
	Silage	85.5	22.5			
	Grain	45.0	41.4			
	Total	155.0	86.1	77.5905	0.13	0.22

TABLE III

FEED AND CHROMIUM OXIDE INTAKE DURING COLLECTION PERIODS

FOR ALL TRIALS, COW 421

Trial No.	Feed	Am'ts. Fed. lb.	Dry Matter lb.	Cr_2O_3 Total g.	Cr_2O_3 % of Total Feed	Cr_2O_3 % of D.M.
1	Hay	95.0	88.2	74.4050	0.17	0.19
2	Hay	47.5	44.0			
	Silage	161.5	35.1			
	Total	209.0	79.1	77.6350	0.08	0.22
3	Hay	35.0	32.1			
	Silage	137.4	27.1			
	Grain	15.0	13.3			
	Total	187.4	72.5	77.5905	0.09	0.24
4	Hay	28.5	25.9			
	Silage	92.5	21.0			
	Grain	30.0	26.7			
	Total	151.0	73.6	77.5905	0.11	0.23
5	Hay	22.5	20.3			
	Silage	78.0	20.6			
	Grain	45.0	41.4			
	Total	145.5	82.3	77.5905	0.12	0.21

TABLE IV

FEED AND CHROMIUM OXIDE INTAKE DURING COLLECTION PERIODS

FOR ALL TRIALS, COW 1404

Trial No.	Feed	Am'ts. Fed lb.	Dry Matter lb.	Cr_2O_3 Total g.	Cr_2O_3 % of Total Feed	Cr_2O_3 % of D.M.
1	Hay	80.0	74.3	74.4050	0.20	0.22
2	Hay	40.0	37.1			
	Silage	136.0	29.6			
	Total	176.0	66.7	77.6350	0.10	0.26
3	Hay	34.0	31.2			
	Silage	134.0	26.4			
	Grain	15.0	13.3			
	Total	183.0	70.9	77.5905	0.09	0.21
4	Hay	29.5	26.8			
	Silage	86.0	19.6			
	Grain	30.0	26.7			
	Total	145.5	73.1	77.5905	0.11	0.23
5	Hay	23.5	21.3			
	Silage	82.0	21.6			
	Grain	45.0	41.4			
	Total	150.5	84.3	77.5905	0.11	0.20

TABLE V

FEED AND CHROMIUM OXIDE INTAKE DURING COLLECTION PERIODS

FOR ALL TRIALS, COW 1405

Trial No.	Feed	Am'ts. Fed lb.	Dry Matter lb.	Cr_2O_3 Total g.	Cr_2O_3 % of Total Feed	Cr_2O_3 % of D.M.
1	Hay	95.0	88.2	74.4050	0.17	0.19
2	Hay	47.5	44.0			
	Silage	158.8	34.5			
	Total	206.3	78.5	77.6350	0.08	0.22
3	Hay	25.0	23.0			
	Silage	80.0	15.8			
	Grain	15.0	13.3			
	Total	120.0	52.1	77.5905	0.14	0.33
4	Hay	26.5	24.1			
	Silage	83.0	18.9			
	Grain	30.0	26.7			
	Total	139.5	69.7	77.5905	0.12	0.24
5	Hay	20.5	18.5			
	Silage	70.5	18.6			
	Grain	45.0	41.4			
	Total	136.0	78.5	77.5905	0.13	0.22

TABLE VI

RATION ANALYSES

Cow No.	Trial No.	Per Cent D.M.	Per Cent of Dry Matter: Nitrogen	E.E.	Fiber	Ash	N.F.E.
1305	1	92.95	2.81	2.08	31.42	8.96	39.98
	2	49.37	2.76	3.24	23.46	10.28	45.77
	3	47.08	2.48	3.74	23.73	7.97	49.06
	4	47.58	2.32	3.57	22.24	7.42	52.27
	5	57.82	2.23	3.89	15.82	7.00	59.38
1321	1	92.85	2.82	2.07	31.41	8.97	39.92
	2	52.37	2.87	3.09	23.16	10.71	45.10
	3	37.94	2.29	4.05	23.78	7.85	50.01
	4	45.71	2.31	3.52	23.05	7.50	51.49
	5	55.55	2.22	3.86	16.72	7.03	58.52
421	1	92.85	2.82	2.07	31.41	8.97	39.92
	2	37.85	2.47	3.64	24.11	9.80	47.01
	3	38.67	2.30	4.00	24.17	7.96	44.49
	4	47.03	2.31	3.55	22.76	7.46	51.79
	5	56.56	2.22	3.88	16.32	7.01	58.89
1404	1	92.85	2.82	2.07	31.41	8.97	39.92
	2	37.90	2.46	3.64	24.06	9.81	47.11
	3	38.74	2.31	4.01	24.06	7.95	49.54
	4	45.26	2.34	3.53	22.71	7.69	51.44
	5	56.01	2.21	3.86	16.52	7.02	58.80
1405	1	92.85	2.82	2.07	31.41	8.97	39.92
	2	38.07	2.46	3.66	24.09	9.76	47.11
	3	43.42	2.38	3.93	22.76	7.70	50.73
	4	47.58	2.32	3.57	22.24	7.42	52.27
	5	57.72	2.23	3.89	15.86	6.99	59.32

TABLE VII

FEED AND WEIGHBACK ANALYSES

Feed	Trial No.	Per Cent D.M.	Per Cent of Dry Matter				
			Nitrogen	E.E.	Fiber	Ash	N.F.E.
Hay	1	92.85	2.82	2.07	31.41	8.97	39.92
	2	92.72	3.32	2.45	22.31	11.74	42.75
	3	91.81	3.02	2.62	29.00	9.61	39.89
	4	90.77	2.83	2.46	32.53	9.33	37.99
	5	20.43	2.89	3.27	28.70	9.91	40.06
Silage	2	21.73	1.39	5.14	26.32	7.36	52.49
	3	19.73	1.39	5.36	26.41	7.91	51.63
	4	22.74	1.40	3.49	29.84	7.21	50.71
	5	26.36	1.31	3.99	23.00	5.35	59.47
Grain	3	88.71	2.45	4.50	7.75	4.17	68.27
	4	89.06	2.53	4.63	7.69	5.88	65.99
	5	91.89	2.35	4.12	6.90	6.40	67.89
<u>Weighbacks</u> Cow No.							
1305	1	92.32	4.00	2.90	16.19	16.75	39.16
1305	2	37.23	3.09	2.60	22.83	14.33	40.93
1321	2	93.06	1.80	1.65	41.91	8.61	36.58
1405	2	40.92	2.90	2.42	26.35	14.57	38.53
421	3	29.95	1.77	4.02	26.79	7.55	50.58
1305	5	53.48	2.29	3.51	18.15	6.90	57.12

TABLE VIII

FECES ANALYSES

Cow No.	Trial No.	Per Cent D.M.	Per Cent of Dry Matter: Nitrogen	E.E.	Fiber	Ash	N.F.E.	Cr_2O_3: % of Total	% of D.M.
1305	1	20.71	2.26	4.85	37.94	14.92	28.16	0.11	0.48
	2	17.48	2.11	5.71	29.96	18.58	32.56	0.10	0.55
	3	16.63	1.93	4.53	32.09	12.48	38.84	0.13	0.77
	4	17.63	2.14	2.98	30.10	13.35	40.19	0.11	0.62
	5	18.72	2.16	3.70	27.92	11.26	43.62	0.11	0.61
1321	1	18.89	2.10	4.32	39.68	14.00	28.87	0.11	0.56
	2	19.45	2.16	5.55	29.29	17.31	34.35	0.08	0.42
	3	16.96	1.89	4.34	31.12	12.02	40.71	0.11	0.65
	4	17.77	2.06	3.82	28.17	12.59	42.54	0.11	0.62
	5	16.66	2.19	3.87	27.22	12.80	42.42	0.10	0.57
421	1	20.43	2.08	4.25	39.99	14.24	28.52	0.13	0.59
	2	16.69	2.07	4.83	26.01	17.57	38.65	0.09	0.56
	3	18.74	2.11	5.96	29.57	12.63	38.65	0.12	0.62
	4	19.76	2.08	3.31	29.90	13.28	40.51	0.14	0.72
	5	20.69	2.10	3.79	22.74	12.39	47.95	0.11	0.55

TABLE VIII (CONTINUED)

Cow No.	Trial No.	Per Cent D.M.	Per Cent of Dry Matter: Nitrogen	E.E.	Fiber	Ash	N.F.E.	Cr_2O_3: % of Total	% of D.M.
1404	1	17.59	2.10	4.74	38.43	15.95	27.75	0.11	0.57
	2	17.52	2.03	4.88	27.17	17.71	37.55	0.10	0.58
	3	14.38	2.16	3.81	29.11	13.30	40.28	0.10	0.67
	4	18.87	2.15	4.06	28.59	13.99	39.92	0.12	0.65
	5	18.42	2.27	3.86	23.42	11.50	47.03	0.10	0.53
1405	1	18.36	1.95	4.09	42.71	13.28	27.73	0.13	0.64
	2	17.75	2.06	4.90	27.87	18.55	35.80	0.12	0.67
	3	19.13	2.16	4.57	31.92	13.10	36.91	0.17	0.89
	4	17.71	2.14	3.52	29.95	12.92	40.23	0.12	0.65
	5	18.10	2.15	4.25	28.12	12.08	42.11	0.11	0.61

TABLE IX

DIGESTIBLE NUTRIENTS IN ALL RATIONS

Cow No.	Trial No.	Protein	E.E.[a]	Fiber	N.F.E.	T.D.N.
		(Per Cent of Dry Matter)				
1305	1	11.06	-0.32	14.03	27.07	51.84
	2	12.94	3.09	13.66	35.11	64.80
	3	11.13	4.70	12.06	34.94	62.83
	4	9.31	5.45	10.59	49.76	75.11
	5	9.06	5.76	5.17	44.20	64.19
1321	1	13.19	1.36	17.95	30.12	62.62
	2	13.13	2.70	12.70	32.83	61.36
	3	9.56	5.20	11.33	33.73	59.82
	4	9.88	4.86	13.06	34.09	61.89
	5	8.56	5.33	5.68	42.67	62.24
421	1	13.44	1.58	18.53	30.74	64.29
	2	10.38	3.92	13.89	31.83	60.02
	3	9.25	3.80	12.72	34.53	60.30
	4	10.31	5.60	12.62	38.85	67.38
	5	8.88	5.47	7.08	41.17	62.60
1404	1	12.56	0.54	16.58	29.21	58.89
	2	9.69	3.26	11.88	30.28	55.11
	3	10.19	6.35	14.94	36.92	68.40
	4	9.88	4.70	12.59	39.05	66.22
	5	8.44	5.40	7.14	41.58	62.56
1405	1	14.00	1.93	18.73	31.69	66.35
	2	11.13	4.61	14.94	35.35	66.03
	3	9.88	5.04	10.92	37.04	62.88
	4	9.56	5.11	11.18	50.47	76.32
	5	9.06	5.31	5.13	44.72	64.22

[a]Figures listed for ether extract have already been multiplied by 2.25.

TABLE X

BODYWEIGHTS FOR ALL COWS, TRIALS I THROUGH V

Date	Cows 1305	1321	421	1404	1405
	lb.	lb.	lb.	lb.	lb.
Oct. 21[a]	806	881	839	810	838
28	825	880	835	817	844
Nov. 4	800	865	840	800	828
11	825	880	866	830	848
18[a]	806	892	869	828	853
25	828	941	873	828	854
Dec. 2	884	963	886	865	891
9	864	967	893	856	904
16	868	977	912	882	906
23	859	955	900	864	887
30	890	979	920	885	915
Jan. 6	892	1007	944	892	900
13	868	972	946	898	887
20	868	984	958	920	894
27	871	976	946	915	879
Feb. 3	901	992	977	918	929
10	901	1006	972	916	915
17	907	1003	973	918	936
24	910	1001	989	926	947
Mar. 2[b]	...	....	...	...	...
9	927	1015	991	938	937
16[a]	939	1045	1014	961	956
Wt. Gain	133	164	175	151	118

[a]Average of weights taken on three consecutive days.
[b]Weights not taken.

VITA

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